JOURNAL OF THE KOREAN INSTITUTE OF ELECTROMAGNETIC ENGINEERING AND SCIENCE, VOL. 10, NO. 1, MAR. 2010 JKIEES 2010-10-1-05

Gain and Phase Mismatch Calibration Technique in Image-Reject RF Receiver

Mi-Young Lee · Changsik Yoo

Abstract

This paper presents a gain and phase mismatch calibration technique for an image-reject RF receiver. The gain mismatch is calibrated by directly measuring the output signal amplitudes of two signal paths. The phase mismatch is calibrated by measuring the output amplitude of the final IF output at the image band. The calibration of the gain and phase mismatch is performed at power-up, and the normal operation of the RF receiver does not interfere with the mismatch calibration circuit. To verify the proposed technique, a 2.4-GHz Weaver image-reject receiver with the gain and phase mismatch calibration circuit is implemented in a 0.18-μm CMOS technology. The overall receiver achieves a voltage gain of 45 dB and a noise figure of 4.8 dB. The image rejection ratio(IRR) is improved from 31 dB to 59.76 dB even with 1 dB and 5° mismatch in gain and phase, respectively.

Key words : Weaver Image-Reject Receiver, Gain Mismatch Cancellation, Phase Mismatch Cancellation, Negative Feedback Loops, Image-Rejection Ratio(IRR), CMOS.

Ⅰ. Introduction

In an RF receiver, the rejection of image signal is often limiting to its selectivity. In a super-heterodyne receiver, the intermediate frequency(IF) is determined considering the image rejection requirement, and is generally too high for the IF band pass filter(BPF) be implemented using CMOS technology. Recently, to overcome this problem, the direct-conversion receiver has been gaining popularity, but its DC-offset and flicker noise problems can limit applicable systems. Low-IF architecture can provide a much higher integration level than a super-heterodyne receiver, and is free of DC-offset and flicker noise problems. However, because of low-IF, image rejection can be very poor unless image signal is rejected by any means. One of the most widely used image rejecting low-IF architecture is the Weaver receiver shown in Fig. 1. In a Weaver receiver, the amount of image rejection is limited by the matching between the signal paths, with a typical level of matching in integrated circuits providing about 30~40 dB of image rejection[1]. If improved image rejection is required, gain and phase mismatch should be calibrated in an adaptive manner. In reference [2],[3], a least-mean square (LMS) algorithm is utilized to calibrate the mismatch and thereby improve the noise rejection. In reference [4], an image tone is applied and the resultant output is detected using an additional detection mixer. The phase and gain mismatch are calibrated until the detected output becomes zero. Although simple, the mismatch calibration information is stored on capacitor and thus the application is limited to a time-division multiple access(TDMA) system. Background mismatch calibration is also possible if additional error signal detection circuitry is provided but power consumption becomes very large[5].

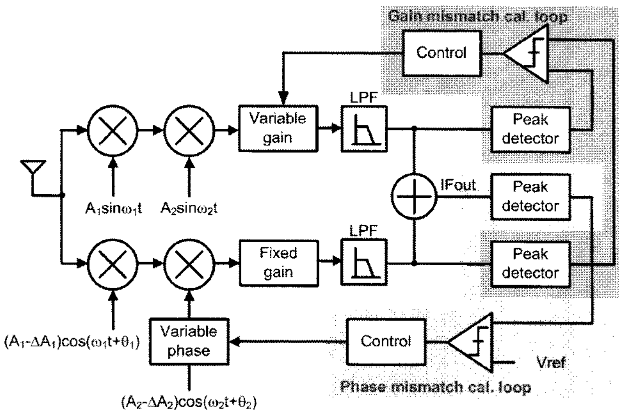


Fig. 1. Weaver receiver with image rejection technique.

This paper presents an image-reject RF receiver based on Weaver architecture. Where the gain and phase mismatches are calibrated independently. At power-up, an image tone is applied, the gain and phase mismatches are calibrated separately, and the result is stored as digital code to be used during the normal operation. After the calibration, all the circuits used to detect the mismatches are turned off to save power. The detailed

Manuscript received January 18, 2010 ; revised February 23, 2010. (ID No. 20100118-002J)
Devision of Electronics & Computer Engineering, Hanyang University Seoul, Korea.

description and the experimental results follow in Section Ⅱ and Ⅲ, respectively; the conclusion is given in Section Ⅳ.

Ⅱ. Image Rejection Receiver with Gain and Phase Mismatch Calibration

In the Weaver receiver shown in Fig. 1, the gain and phase mismatches between the in-phase(I) and quadrature-phase(Q) signal paths limit the image rejection. For the RF input at the image band, $x(t)=A_{IM}\cos\omega_{IM}t$, the output signal is given as:

$$y(t)=\frac{A_{IM}}{4}(A-\Delta A)\cos(\omega_{IF}t+\Delta\theta)-\frac{A_{IM}}{4}\cdot A\cos\omega_{IF}t \quad (1)$$

where $A=A_1A_2$ is the total gain, $\Delta A=\Delta A_1A_2+A_1\Delta A_2$ is the total gain mismatch, and $\Delta\theta=\theta_1+\theta_2$ is the total phase mismatch.

To improve image rejection, the proposed image-rejection receiver shown in Fig. 1 measures the gain and phase mismatches and calibrates them independently. At power-up, a single-tone at the image band is applied to the RF input, and the resultant IF output is utilized to calibrate the gain and phase mismatches.

For gain mismatch calibration, the output amplitudes of the second mixers of the I- and Q- paths are compared and the gain is calibrated until the two output amplitudes become the same using a negative feedback loop. The signal amplitudes can be detected by a full-wave rectifier and the phase calibration loop is disabled during the gain calibration. If the gain mismatch is completely calibrated, the output signal is:

$$y(t)=\frac{A_{IM}A}{4}\cos(\omega_{IF}t+\Delta\theta)-\frac{A_{IM}A}{4}\cos\omega_{IF}t$$
$$=\frac{A_{IM}A}{4}(\cos\omega_{IF}t\cos\Delta\theta-\sin\omega_{IF}t\sin\Delta\theta-\cos\omega_{IF}t) \quad (2)$$

and the output amplitude is proportional to the phase mismatch. Therefore, the phase mismatch can now be calibrated by detecting the output signal amplitude. The output amplitude is detected using a full-wave rectifier and the phase of the second LO input is calibrated so that the amplitude becomes the minimum while the gain calibration loop is disabled.

Because the gain mismatch is calibrated by changing the gain of the IF mixer, as shown in Fig. 2[3], it has the capability of variable gain. The gain control voltage, V_{gain}, is generated by the mismatch calibration loop. The phase of the second LO is varied so the phase mismatch between the I- and Q- paths are eliminated. To change the phase of the second LO, the second LO buffer has a variable phase delay, which can be controlled by the phase control voltage. The variable phase delay is realized by interpolating the two LO signals, each of which has small and large delays from the input as shown in Fig. 3[3]. The interpolating weight is controlled by the phase control voltage, V_{phase} which is generated by the phase mismatch calibration loop.

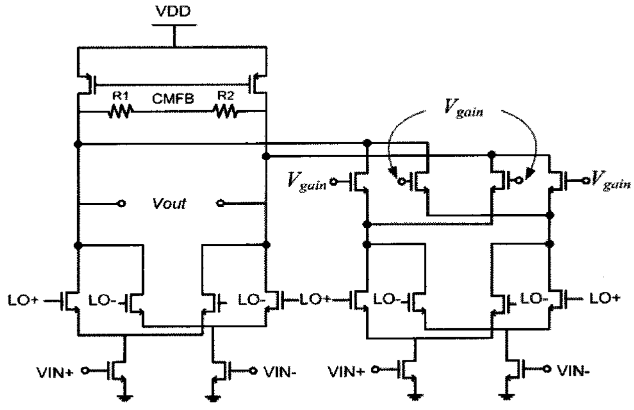


Fig. 2. IF mixer and variable gain circuit.

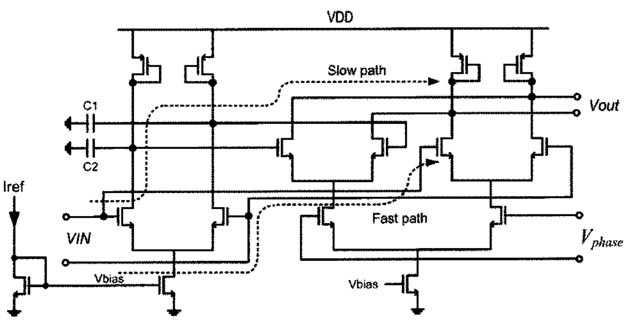


Fig. 3. Variable phase circuit.

Ⅲ. Experimental Results

In order to verify the proposed gain and phase mismatch calibration technique, the receiver shown in Fig. 4 has been measured with the assumption of 1 dB and 5° mismatch in gain and phase, respectively, between the I- and Q- paths. The receiver is implemented in a 0.18-μm CMOS process and tested with a 1.8 V supply.

The RF input signal has two tones, each of which is located at the signal band(2.44 GHz) and image band (2.2398 GHz), respectively. The first and second LO signal frequencies are 2.34 GHz and 90 MHz, respectively. In Fig. 5(a), the measured output spectrum before the calibration is shown and the image rejection ratio(IRR) is only 31 dB. After the calibration, the IRR is improved to 59.7 dB as shown in Fig. 5(b). Fig. 6 shows the IRR as a function of the RF input frequency with the proposed mismatch calibration enabled.

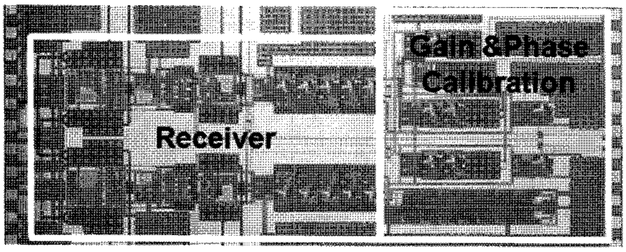
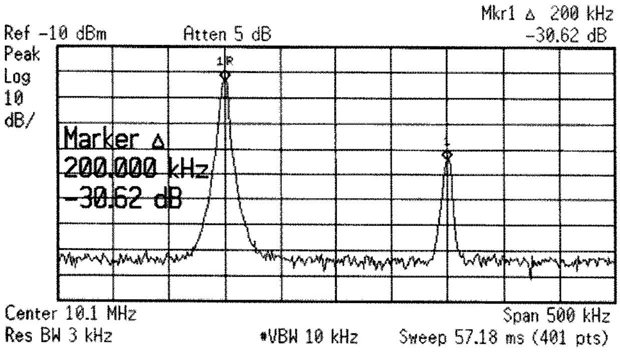
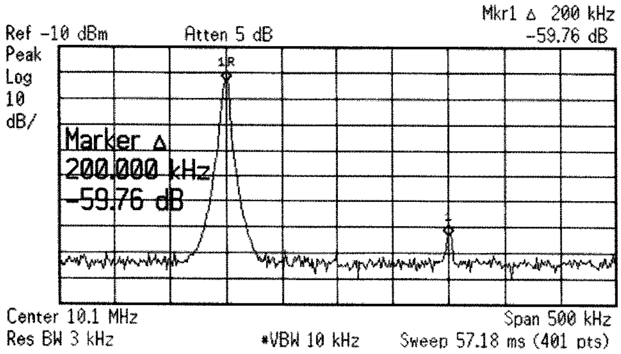


Fig. 4. Die photograph.



(a) Before calibration



(b) After calibration

Fig. 5. Measured IRR.

Ⅳ. Conclusion

A gain and phase mismatch calibration technique for image-reject RF receiver is proposed. In this paper, an image tone is applied, gain and phase mismatches are calibrated separately, and the result is stored as digital code to be used during the normal operation. After the calibration, all the circuits used to detect the mismatches are turned off to save power. The calibration of the gain and phase mismatch is performed at power-up, and the normal operation of the RF receiver does not interfere with the mismatch calibration circuit. A 2.4-GHz Weaver image-reject receiver with the proposed gain and phase mismatch calibration circuit is implemented in a 0.18-μm CMOS technology. The image rejection ratio(IRR) is improved to 59.76 dB, even with 1 dB and 5° mismatch in gain and phase, respectively.

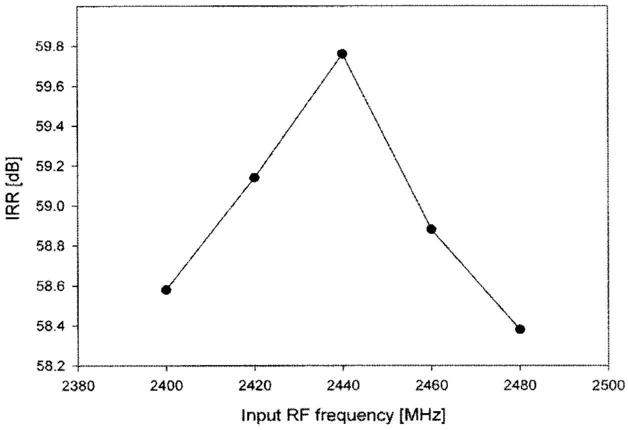


Fig. 6. IRR performance versus RF input frequency.

Table 1. Comparison with other works.

	Ref. [3]	Ref. [4]	Ref. [5]	This work
Tech.	0.25-μm	0.35-μm	0.35-μm	0.18-μm
VDD	2.5 V	3 V	3 V	1.8 V
Power (During signal reception)	50 mW	105 mW	95 mW	45 mW
Power (During calibration)	55 mW	170 mW	160 mW	50 mW
IRR	57 dB	57 dB	59 dB	59.76 dB

References

[1] J. Crols, Michel S. J. Steyarert, "A single-chip 900 MHz CMOS receiver front-end with a high performance low-IF topology", *IEEE J. Solid-State Circuits*, vol. 30, no. 12, Dec. 1995.

[2] L. Yu, M. Snelgrove, "A novel adaptive mismatch cancellation system for quadrature IF radio receivers", *IEEE Trans. Circuits Syst.* II, vol. 46, pp. 789-801, Jun. 1999.

[3] L. Der, B. Rajavi, "A 2-GHz CMOS image-reject receiver with LMS calibration", *IEEE J. Solid-State Circuits*, vol. 38, no. 2, pp. 167-175, Feb. 2003.

[4] R. Montemayor, B. Razavi, "A self-calibrating 900 MHz CMOS image-reject receiver", in *Proc. ESSCIRC*, pp. 320-323, Sep. 2000.

[5] M. A. I. Elmala, S. H. K. Embabi, "Calibration of phase and gain mismatches in weaver image-reject receiver", *IEEE J. Solid-State Circuits*, vol. 39, no. 2, pp. 283-289, Jan. 2004.